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Antibiotic-Producing Fungi: Current Status of Nomenclature

C. W. HESSELTINE[1] AND J. J. ELLIS[2]
Northern Regional Research Laboratory, Peoria, Illinois

I. Introduction

This topic is perhaps too restrictive for the material we shall include. Although emphasis will be on nomenclature of antibiotic-producing fungi, we shall discuss more broadly the problem of nomenclature for fungi used in industrial fermentations. We also shall indicate some areas of mycological nomenclature that may be changed in the near future in the Botanical Code, which covers fungi.

II. Antibiotic-Producing Fungi

Although there are a large number of species of fungi, only a relative few have been found to produce antibiotics, and only seven antibiotics are produced commercially. The 1970 Information Bulletin, No. 8 (*3*) of the International Center of Information on Antibiotics lists 338 species of fungi that produce antibiotics. According to 1967 (*11*) and 1970 (*13*) lists assembled by Perlman, the following antibiotics are produced commercially: Fusidic acid formed by *Fusidium coccineum* Fückel, griseofulvin formed by *Penicillium griseofulvim* Dierk, penicillins formed by *Penicillium chrysogenum* Thom, variotin formed by *Paecilomyces varioti* Bainier, derivatives of cephalosporin formed by *Emericellopsis* (*Cephalosporium*), and fumagillin produced by *Aspergillus fumigatus* Fres. Since then, siccanin produced by *Helminthosporium siccans* Drechsler has been produced in Japan. According to Perlman (*12*), only three groups of antibiotics are produced by fungi in the United States. These are the cephalosporins, penicillins, and fumagillin.

[1] Chief, Fermentation Laboratory, Northern Regional Research Laboratory, Peoria, Illinois.

[2] ARS Culture Collection Research, Fermentation Laboratory, Northern Regional Research Laboratory, Peoria, Illinois.

III. Rules of Botanical Nomenclature

Fungi, including Myxomycetes, Phycomycetes, Ascomycetes, Basidiomycetes, Lichens, and Fungi Imperfecti, are covered by the International Code of Botanical Nomenclature (*6*). This code covers all plants. It originated in 1906, although a set of rules for nomenclature was published in 1867. Since then, the rules have been improved and revised in 1912, 1935, 1947, 1950, 1952, 1956, 1961, 1966, and finally 1972. References to all these codes appear at the end of the Botanical Code published in 1972. Generally, a new code is published after each Botanical Congress. The code consists of a Preamble, Principles, Rules, and Recommendations; it lists both conserved and rejected taxa; it is published in English, French, and German. In the 1972 Code, 58 genera of fungi are conserved exclusive of Lichens. The only name of importance to industrial fermentation is the genus *Candida* Berkhout, which is conserved over all its synonyms.

Initially, the rules of Botanical Nomenclature were considered at the First Botanical Congress held in Paris in 1867. These rules were primarily for vascular plants but also included bacteria and fungi. It was not until 1947 that bacteriologists broke away from the Botanical Code, primarily because the Botanical Code stated that living cultures are not acceptable as types. The Botanical Code specifies that a type specimen of a taxon of recent plants, the bacteria excepted, must be preserved permanently and cannot be a living plant or culture. The International Code of Nomenclature of Bacteria (*7*) incorporates many rules that apply to the Botanical Code.

IV. Purpose of the Botanical Code

The Botanical Code arose to satisfy a need for an orderly manner of naming taxa. As Shear (*17*) states, "the fundamental requirements of a satisfactory nomenclature are uniformity, stability, exact application and convenience."

The Botanical Code, as set forth in the Preamble:

1. Establishes a precise and simple system of nomenclature to be used in all countries.
2. Establishes a stable method of naming taxonomic groups.
3. Tries to avoid the useless creation of names.
4. Establishes rules (articles), which must be followed, and recommendations. Recommendations deal with subsidiary points; their objective is to bring about greater uniformity and clearness, especially in future nomenclature.

5. Recommends, in the absence of a relevant rule or where the consequences of rules are doubtful, following established custom.

Examples of the application of the rules and recommendations are cited after each rule and recommendation. Since fungi offer certain special problems, some rules are specifically designed for fungi.

V. Numbers of Fungi

One can ask how many fungi actually exist which are covered by the Botanical Rules. Of course, there are hazards in estimating the number of fungi. The figure most frequently quoted is 100,000 species. This number is evidently based on the total compiled in Saccardo's *Sylloge Fungorum*, Volumes 1 through 25 (*15*), plus an estimate of those proposed since. Martin (*10*) considered this figure to be "excessively conservative." He based his statement on an exercise of randomly selecting 100 vascular plants and finding from Seymour (*16*) the number of different fungi that parasitized them. The result indicated an average of three fungi per host species. Martin suggested that, if to the total number of parasitic fungi is added the number of saprobic fungi, the number of good species of fungi is at least as great as the number of Phanerogams (vascular plants). The number of Phanerogams is believed to be about 250,000. According to Ainsworth (*1*) the number of proposed new species of flowering plants is now static or on the decline. However, new species of fungi proposed averaged 700 per year between 1920 and 1950. Currently, the *Index of Fungi* (*5*) lists more than 1000 newly proposed names each year with about half of them redispositions.

VI. Botanical Rules Specifically for Fungi

Botanical rules of nomenclature that specifically deal with fungi include an article on the names of fungi with a pleomorphic life cycle. The pleomorphic life cycle refers to fungi that may have two or more spore states. The mold that produces cephalosporins exhibits such a life cycle. Consequently, the fungus that produces these compounds was first described as a species of *Cephalosporium* because only the conidial or asexual stage was known. Later the ascosporic or sexual (perfect) stage was found, which belonged to the genus *Emericellopsis* (*4*). Commonly, the fungus grows as a *Cephalosporium*, and only under certain conditions will it produce sexual spores. The valid name for a fungus having a pleomorphic life cycle is the earliest legitimate name typified by the perfect state, but the name of the imperfect state can be used for convenience. Hence, it would be correct to say that *Emericellopsis* has a *Cephalosporium* imperfect state for the species that produces the cephalosporins.

A second section of one article in the Botanical Code lists the starting dates for the nomenclature of fungi. The starting date for certain fungi belonging in the Basidiomycetes begins with Persoon's book *Synopsis Methodica Fungorum,* 1801. The starting date for Myxomycetes and Lichens begins with Linnaeus' *Species Plantarum,* 1753, and the date for the remaining fungi begins with Fries' *Systema Mycologicum,* 1821. The third starting date is the one particularly important to fermentation researchers because almost all fungi concerned started at that date or later. Incidentally, the Botanical Code states that the nomenclature of bacteria begins with Linnaeus' *Species Plantarum,* 1753. (The Bacteriological Code likewise begins with Linnaeus.) To us, 1753 is a poor starting date for bacteria because Linnaeus was unaware of bacteria and had only a fuzzy idea of what fungi were. A date after 1900 based on a treatment of all bacteria would be a much more reasonable and effective one. The proposed new Code for Bacteria (9) is just as inappropriate because it states that the starting date should be moved to January 1, 1980. One wonders why 1984 might not have been suggested. The Botanical Code can be revised only at International Congresses, and the manner in which it can be revised is clearly stated.

In the Botanical Code the type specimen is clearly defined: It states that a type specimen is a preserved specimen, not a living culture. For example, when we have described a new species of mold, a dried culture is designated the type, and it, or portions of it, are deposited in a herbarium. A type culture is not recognized in the Botanical Code because it can change in appearance with repeated transferring or it may actually be lost. For many fungi, designating a culture or type offers certain difficulties.

Of course, there are other examples of the rules dealing with fungi, but they are of little concern to us here.

VII. Comparison of the Botanical and Bacterial Codes

In Table I are given some differences between the Botanical Code and the Bacterial Code. It is appropriate to make some generalizations about the two codes as they affect applied microbiology. Since the Botanical Code has been in existence for a longer time, it is more stable and the points of controversy are fewer. For example, in the next Botanical Congress, the five issues or problem areas (8) as applied to fungi are as follows: (i) whether or not a type culture should be designated for fungi (we believe that this defect is the only serious major one in the Code that needs to be corrected); (ii) clarification of the rule that deals with pleomorphic fungi; (iii) clarification of starting dates and problems of overlap of groups with different starting

TABLE I

SOME COMPARISONS OF THE BOTANICAL AND BACTERIOLOGICAL CODES

Description	Botanical code	Bacteriological code
Starting date of nomenclature	Lichens, Myxomycetes: Linnaeus' "Species Plantarum" May 1, 1753 Uredinales (rusts), Ustilagenales (smuts), Gastromycetes (puff balls): Persoon's *Synopsis Methodica Fungorum* December 31, 1801 Fungi, Caeteri (all other fungi): Fries' *Systema Mycologicum* January 1, 1821	Linnaeus' *Species Plantarum*, May 1, 1753. It is proposed to set this date as January 1980
Language	After January 1, 1935 must be accompanied by a Latin description or diagnosis	None. Proposed code would require a description in a familiar language
Type	"Type specimen . . . must be preserved permanently and cannot be a living plant or culture." If it is impossible to preserve a specimen, then "the type may be a description or figure"	A designated type strain or in special cases a description, preserved specimen, or illustration. Proposed code: Wherever possible a strain of a living culture. If no living culture is available, a later cultured strain may be designated as a neotype
Effective and valid publication	Distribution of printed material must be accompanied by a diagnosis or reference to a previously effectively published description. After January 1, 1933, no name proposed in a tradesman's catalog or in a nonscientific newspaper is valid	Printed matter for sale or distribution to the general public or bacteriological institution is valid. Inclusion of a name in a patent is not effective publication
Pleomorphic life cycle	Pleomorphic life cycles in Ascomycetes and Basidiomycetes are recognized. The valid name is the "earliest legitimate name typified by the perfect state," but names of imperfect states can be commonly used	Nothing
Provision for emendment of	Modified by act of plenary session. Provides for 11 permanent nomenclatural committees and includes a "Committee for Bacteria"	Modified by action of the International Committee on Nomenclature and approval of a general meeting

dates; (iv) provision for handling intraspecific taxa not covered by the Code; (v) registry of new names and proposals for conservation.

The starting dates of bacteria, both proposed and the current ones, seem to be unreasonable. For fungi, the starting dates have been fixed for a long time and are generally quite satisfactory. Such genera as *Penicillium* and *Aspergillus* were described in Fries, and reference is made to illustrations that clearly depict the same organisms we know as these genera today. At least some of the species recognized by Fries are *Penicillium* and *Aspergillus* in the modern sense.

Exclusion by the Bacteriological Code of patents as vehicles to publish bacterial names is most unfortunate. In the Botanical Code publication of names in patents is permitted since the article states, "Publication is effected, under this Code, only by the distribution of printed matter (through sale, exchange or gift) to the general public. . . ." It specifically excludes publication "in tradesmen's catalogs and nonscientific newspapers." Since patents are not in these categories but are part of the scientific literature, are printed, and are available for sale, descriptions of fungi in patents, provided a Latin diagnosis is given, are effectively and validly published.

Because the procedure for amending the rules is clearly defined in the Botanical Code, whenever changes are proposed they are seriously studied. The consensus of many people is required before additions or deletions can be made. In contrast, it appears that a few people have been able to control changes in the Bacteriological Code.

The requirement for a Latin description included in the Botanical Code has certain distinct advantages even though the language is no longer a common everyday one. However, with the use of a dictionary, almost everyone can read a simple Latin diagnosis. Taxonomists the world over use this procedure, and even though it is impossible for most Western people to read articles written by either Russians or Japanese, these people give Latin descriptions that can be understood everywhere. To Latinize a description requires some skill, but often help can be obtained from friends who are expert in Latin or from faculty members in classical language departments. Because a Latin description is required, persons naming new taxa must be serious about the new names they are proposing.

A special problem in industrial mycology involves the nomenclature of induced mutants that may be very different in appearance from their wild-type ancestors. The mutants should retain the species name of the wild-type material. However, the Botanical Code has a section devoted to "Names of Plants in Cultivation" in which variants produced by hybridization, mutation, or selection are of sufficient interest to receive epithets preferably in common language (i.e., fancy epithets) markedly

different from the Latin epithets of species and varieties. It cites several examples such as *Primula malacoides* 'Pink Sensation.' Normally in microbiology a strain number is used, not a fancy name.

Part of the reason for differences between the Botanical and Bacteriological Codes is that species, and even varieties, of fungi are described on morphological grounds, whereas almost all the descriptions of bacteria are physiological.

VIII. Descriptions of Fungi

Some may wonder what an adequate taxonomic treatment of a new fungus should be. First, it should cite the name to be applied and the appropriate taxon designation; for example, sp. nov., which means that the authors consider it to be a new species. Following this designation should be given the synonyms or names that are not valid and the citations to where these were used first in the literature. Next comes a description that typically gives the colony appearance, including color on three or four media, which can be reproduced readily in other laboratories. Color of the colonies on each medium should be described from a color chart at various ages and for both the top and bottom of the colony. Then a description of the microscopic characters of the fungus on one or more of the media should be given. Development of structures and their mature appearance should be described. Measurements of the size of all the morphological parts should be listed, including the minimum, maximum, and average dimensions. Generally, this information should include the range and the average of at least 100 measurements. If there is a sexual state, it should be described and the conditions under which it was induced to form should be given. The description should give the data on physiological characteristics, such as the growth at different temperatures, sugars fermented or utilized, and other similar traits.

In a separate paragraph the location of the type material, who collected it, and the date it was collected should be reported, followed by a statement indicating where the type specimen was deposited. A type strain and its deposit number in an established culture collection can be named here. Because the designation of a type strain number is not prohibited by the Botanical Code, we believe a culture should be so designated, and every attempt made to have the culture preserved. The Latin diagnosis should follow the formal description in a common scientifically used language. Often, it is put first rather than after and it needs to only cover the more important characteristics of the taxon. Some prefer to repeat the complete description in Latin.

Next should appear a statement indicating the origin of the new name

(its etymology). This statement should precede a description of the geographic range of the fungus, so far as is known, and the host specificity if it is a parasite. Next comes a general discussion of how many specimens or strains were studied and their sources. If there is any question as to which family it belongs, the authors should indicate the family to which they think it belongs and their reasons for placing it there.

How the new taxon differs from its most closely related species needs to be discussed, including an enumeration of the characteristics that make it distinct. Sometimes it is helpful to give a diagnostic key to the genus or portion of the genus to show how the species differs from all other known species. Information needs to be provided as to how stable the various characteristics may or may not be. Also, there needs to be information on additional strains and specimens studied and how any of these differ from the type as well as how the species differs from other species studied for comparative purposes.

The description of each new taxon requires illustrations (either photographs or line drawings) including microscopic details. Finally, the description and name must be both validly and effectively published according to the International Code of Botanical Nomenclature (*6*).

IX. Type Cultures in Culture Collections

Because we are dealing here primarily with fungi used in industry, and particularly in the antibiotic industry, the subject of deposit of cultures, especially those in connection with patent applications, needs to be discussed. Deposits need to be made in good permanent collections whose standards are quite high. Along with Drs. Creech and Warwick (*2*), one of us (CWH) has attempted to give the characteristics of superior culture collections in the report *Genetic Pools. The Conservation of the World's Genetic Resources in Plants, Animals, and Microorganisms for use in Agriculture and Industry.* These characteristics are repeated here:

1. The collection must be part of, or closely related to, a research laboratory concerned with either microbiology or fermentation, or both. For example, at the Northern Regional Research Laboratory, Peoria, Illinois, the ARS Culture Collection is one of four research units in the Fermentation Laboratory. Interactions between microbiologists and culture collection curators work to the mutual benefit of both. The microbiologist, being aware of general trends in microbiological research, is able to anticipate future areas of interest and to give guidance as to what microorganisms a culture collection should accession to meet future needs. The curator, with his knowledge of the relationships among genera

and the physiological requirements of various microorganisms, can make valuable suggestions in return.

2. A culture collection must be well funded, and this funding must be at a relatively uniform level each year. In many research operations, a program may be increased or decreased readily with changes in the amount of budgeted money. People can be shifted easily from one project to another. A culture collection, on the other hand, is a continuing operation that must be sustained without great fluctuations in either budget or people from year to year.

3. A culture collection must have adequate facilities and equipment, including transfer rooms, refrigerator space, incubators, microscopic and photographic equipment, autoclaves, and lyophilizers. Usually these facilities should be separate from those of other research groups.

4. Library facilities are necessary so that the staff may have access to the taxonomic and microbiological literature being published not only in the region or country of location, but also elsewhere in the world.

5. The collection should have an active and continuing program of isolating new strains of microorganisms from nature. Such a program will lead to the discovery of new products and reactions. New material will add to understanding the classification of special groups of microorganisms and will make it possible to discover species and genera new to science.

6. The collection must have an adequate staff to support the curators. By this is meant technical help for the preparation of media, sterilization of glassware, maintenance of supplies, and similar service duties; secretarial help to keep the voluminous records and to handle correspondence; and shops to construct special apparatus. Reliable sources of supplies are also necessary.

Optimally, each curator should have a careful, intelligent, and dedicated assistant with some microbiological training. Technicians need not be too specialized because they always must be trained in the special techniques required by each group of microorganisms. Assistants should handle periodic transfers, lyophilization and associated records, inoculation of cultures for study by the curator, seeding of flask cultures for preliminary surveys for new products, and making and recording routine observations on all cultures.

7. The curator(s) must do research as well as culture maintenance. Each must have an active research program either in taxonomy or in genetics, with preference to the former. Thus a curator will have an intimate knowledge of the strains he is maintaining and will develop a reputation as an expert in his field. Consequently, important material will be sent to him for safekeeping, for identification, and for other purposes. Other microbiologists will know from whom they may get

expert advice, cultures, or materials to isolate cultures from. Culture collection people not only should engage in research, but they should report their research in the form of papers published in scientific journals, give lectures, and occasionally take out initial patents.

8. College-trained men and women in collections must be aware of the field of basic and applied microbiology and have an appreciation of fermentation research and development. They must comprehend the problems of geneticists, fermentologists, engineers, biochemists, and organic chemists. Probably the most difficult job from the standpoint of the administration of a culture collection involves indoctrination of the curators in understanding other scientists' point of view, and bringing them to realize that they are part of a team working toward established goals whether in producing a product for sale or in the discovery of new information about microorganisms. Collection staff must be made aware of the needs of other research people.

9. Although the curators should be trained in taxonomy, the overall background of the staff should have balance. If the collection has more than one senior scientist, then the broader the interests of the group the better. It does no good to have three specialists on bacteria and yet have no mycologists, or vice versa.

10. At least in the larger collections, young people with new ideas and knowledge of new techniques should be brought into the group periodically. This means of rejuvenation may be supplemented with postdoctoral fellows and exchange of personnel from other institutions. They should not necessarily be people from other collections. In turn, the resident staff needs periodically to travel or study in other laboratories.

X. Publications Dealing with Fungal Nomenclature

Proposals for modifying the Botanical Code are published in *Taxon*, the official organ of the International Association for Plant Taxonomists. These modifications are periodically voted on by the membership and can be accepted, rejected, or referred to a committee. Conserved fungus names have also been published in *Taxon*. The names of fungi can most easily be found in two references. The first is Ainsworth's *Dictionary of the Fungi* (*1*), which gives all generic names, including lichens up to 1970. Synonyms are referred to their proper genera. Generally, a reference to a monographic treatment of the genus or to a recent treatment of the species is given. The second reference is the *Index of Fungi* (*5*), which is published periodically—twice a year lately. The *Index of Fungi* is a continuation of Petraks' Lists (*14*), which contained names of fungi up to 1940. These two references give the place of publication

of the species of fungi, and the *Index of Fungi* includes references to new species as they are proposed.

It is to be hoped that future International Botanical Congresses will devise a logical and methodical means of correctly solving the nomenclatural problems confronting us.

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